PhD proposal

Climate change and heat waves in an urbanized valley: adaptation scenarios and impact on air quality

27 June 2021

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Dates: 1st October 2021 - 30 September 2024

Location: Grenoble, France

Skills requested: good knowledge of fluid mechanics; basic knowledge of atmospheric dynamics; experience in numerical modelling and data analysis; good command of English, basic knowledge of French.

Application process:

- Applications should be submitted by **16 July, 1 pm** (Paris time).
- Please send your CV to Chantal.Staquet@univ-grenoble-alpes.fr. Also include in your CV the courses you have taken in relation to the thesis topic, as well as your academic results (Bachelor and Master).
- **If your application is selected**, the following documents will be requested: two recommendation letters; a motivation letter stating why your background is particularly suitable for the thesis topic.

Abstract: This thesis proposal concerns adaptation to climate change during heat waves in the 21st century in the Grenoble metropole. Climate change will increase the frequency and intensity of heat waves over the course of the century. Temperature reduction measures, which are well known in hot regions, have been implemented in metropoles, such as the increase of roof albedo or the extension of green areas. However, recent literature shows that ozone and fine particle pollution can be increased by these measures. The objectives of the thesis work are (i) to characterize the atmospheric dynamics and temperature distribution in the Grenoble metropole during heat waves over the century and (ii) to determine adaptation measures to climate change aimed at reducing the temperature at the valley bottom while preserving air quality. The results obtained will be transferred to local decision-makers through regular meetings.

1. Context and motivations

It has now been established that climate change will increase heat wave episodes in France (Bador *et al* 2017). Predictions for France up to the end of the century show that the intensity of these episodes will increase over time, with a strong sensitivity to the socio-economic pathway considered (Météo-France report, DRIAS 2020). For the most unfavourable pathway, called SSP5 and associated with the continuation of strong competition between countries (energy consumption and greenhouse gas emissions are at their highest), the number of heat wave days is increased by a factor of 5 to 10 compared with the 1976-2005 reference period. This factor depends on the region considered, with the south-east part of France being the most affected.

Over the past 30 years or so, "regional" effects of climate change, at the scale of a country or a mountain region, have been the subject of a considerable effort at an international level (Giorgi 2019) as illustrated by the Euro-Cordex network for Europe (for instance, the report of Météo-France mentioned above is based on the Euro-Cordex database). Further downscaling to the scale of large urban sites such as Porto (Rafael *et al* 2020) or London (San Jose *et al* 2018) has recently been performed. The objective of the two latter studies is to estimate the impact of climate change during heat waves in terms of temperature levels, air quality and health effects. For Porto, scenarios of temperature mitigation measures around 2050 are also studied by changing urban design (reflective roofs, increased green spaces). For London, a strong heterogeneity of the temperature field in the city is predicted at the end of the century, with a higher impact on health of the large temperature values than of pollution. Temperature values in these metropoles during heat waves at the end of the century are therefore a key factor for habitability.

As shown by Fallman *et al* (2016) for the city of Stuttgart during the 2003 heat wave or Rafael *et al* (2020) for Porto around 2050, the implementation of temperature mitigation measures requires to question their impact on air quality. Indeed, the use of reflective roofs alone increases the average ozone concentration because the increased solar radiation favors photochemical reactions which cause ozone production. A combination of vegetated and reflective roofs reduces the average ozone concentration but, by stabilizing the atmospheric boundary layer, increases the concentration of primary pollutants.

Many metropoles are located in mountainous terrain, such as Kathmandu in Nepal, Bogota in Colombia, Lanzhu in China or Grenoble, for which the role of orography in the impact of climate change is not known. The aim of the thesis work is to tackle this issue during heat wave episodes around 2050 and 2070 for the Grenoble metropole. Both fundamental and applied issues will be addressed. Indeed the thesis work will focus on (i) the characterization of the atmospheric dynamics and temperature distribution in the Grenoble valley during heat waves around 2050 and 2070; (ii) determining mitigation measures of temperature at the valley bottom; (iii) the impact of these measures on air quality. The latter point is part of the more general concern that actions to reduce or adapt to climate change should also preserve air quality (Schmale *et al.* 2014).

2. Organisation of the thesis work

Atmospheric dynamics in the Grenoble valley during heat waves around 2050 and 2070

The heat wave episode of summer 2003 in the Grenoble valley will first be numerically simulated and serve as a reference. The main objective of this simulation is to assess the validity of the numerical modelling by comparison with field data. This simulation will also allow to address the main issues considered in the future. Thus, the distribution of the temperature field near the ground (particularly at the bottom of the valley) and the analysis of its heterogeneity, in relation to topography, soil humidity or heat fluxes in the valley, will be studied. The height of the boundary layer and the vertical transport of matter and heat above the valley will also be evaluated as well as the atmospheric circulation in the valley. It should be noted that only one study related to atmospheric dynamics has been published for the Grenoble valley for the 2003 heat wave episode, which was mainly focused on the production and transport of ozone during the episode (Chaxel and Chollet 2009).

Extreme heat waves around 2050 and 2070 will then be simulated numerically using a methodology specified in section 3. Compared to the 2003 heat wave, the objectives will be to investigate whether the temperature distribution near the ground has changed, how and why its intensity has varied, the new characteristics of vertical transport and more generally of the atmospheric circulation in and above the valley.

Adaptation scenarios to climate change in the Grenoble valley during heat waves

For the case of the extreme heat waves just mentioned, the impact of temperature mitigation measures at the valley bottom will be investigated via urban planning scenarios, such as increasing the surface of green areas or the roof albedo (is it sufficient to act on the hottest zones inferred from the study of temperature heterogeneity to reduce the temperature at the bottom of the valley?).

Impact of adaptation scenarios on air quality

The last objective of the thesis work is to analyse the impact of the urban planning scenarios on air quality for a current emission inventory. If air quality deteriorates, which is very likely according to the literature, a new emission inventory (with lower emissions) will be considered, using the most favorable urban planning scenario in terms of temperature reduction. This new emission inventory will be defined jointly with the local authority.

The results obtained during the PhD work will be transferred to local decision makers through regular meetings.

3. Methodological aspects

Atmospheric dynamics in the Grenoble Valley will be studied by numerical modelling based on the WRF (Weather Research and Forecast) numerical model, which our group has been using for about ten years.

For realistic numerical simulations of the Grenoble valley in the future, a chain of models will be used, formed by the WRF model forced at its boundaries by the MAR (Modèle Atmosphérique Régional) model, itself forced by the MPI climate model for the SSP5 scenario. The WRF model will be at high resolution, about 100 m horizontally for its innermost domain (a classical nested model technique will be used to go down from the 7 km resolution of the MAR model to 100 m). The MAR model was developed by Gallée and Schayes (1994). The MPI model, developed by the Max Planck Institute in Germany, is one of the climate models of the latest intercomparison program of climate models (CMIP6). The WRF ← MAR ← MPI chain of coupled models was developed in our group in collaboration with the IGE[1] in Grenoble.

The implementation of urban planning modifications (increase of green areas and of roof albedo) will be based on the methodology developed with the WRF model by Rafael *et al* (2020). This work will be carried out in collaboration with the Grenoble urban planning agency and with Alain Clappier, who is a specialist in urban climate and urban air quality.

The air quality study will be carried out by coupling the WRF model with the CHEM chemistry model (this coupling has already been performed by LEGI). The CHEM model will be initialized with the help of the air quality agency. This task will also be performed in collaboration with Alain Clappier.

The calculations will be carried out on massively parallel supercomputers of French national computing centres.

[1] IGE: Institute of Geosciences and the Environment

4. Collaborations

This thesis topic is part of a project funded by the French Institute ADEME[2]. This project started on October 1st, 2020 and is three-year long. This is an interdisciplinary project dealing with the impact of climate change on pollution in the Auvergne Rhône-Alpes region and on temperature levels during heat waves in the Grenoble metropole. Scenarios concerning the reduction of pollution at the regional scale and of temperature at the metropole scale around 2050 will be considered, followed by a study of their health impact and a cost-benefit analysis.

The project partners are climatologists (Hubert Gallée and Martin Ménégoz, IGE), expert in fluid dynamics (C. Staquet), epidemiologist (Rémy Slama, IAB[3]) and environmental economist (Sandrine Mathy, GAEL[4]). The Auvergne Rhône-Alpes region air quality agency and the Grenoble urban planning agency will also be partners of the project.

The thesis work will be performed in close collaboration with Martin Ménégoz and Hubert Gallée. Other collaborators will be Alain Clappier, professor at the University of Strasbourg and Charles Chemel, senior researcher in England at NCAS[5] and the University of Leeds.

5. **Références**

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- San José R., J. L. Pérez, L. Pérez, R. M. G. Barras 2018 Effects of climate change on the health of citizens modelling urban weather and air pollution, *Energy*, 165, Part A, 53-62.
- Schmale J., D. Shindell, E. von Schneidemesser *et al.2014* Air pollution: Clean up our skies. *Nature* **515,** 335–337.

[2] ADEME: French Agency for Environment and Energy Management
[3] IAB: Institute for the Advance of Biosciences
[4] GAEL: Grenoble Applied Economy Laboratory
[5] NCAS: National Center for Atmospheric Science